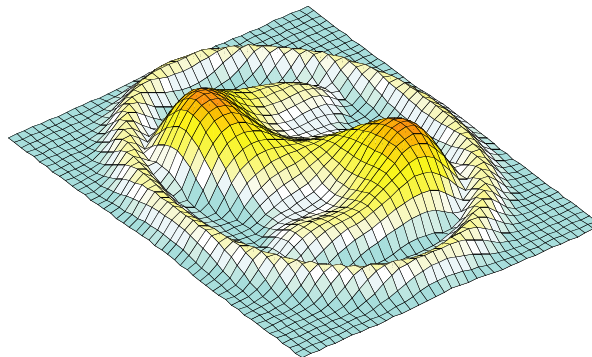


# Surface Operation Automation Research — SOAR —

**Dr. Victor H. L. Cheng**  
**Optimal Synthesis Inc.**  
**Palo Alto, California**

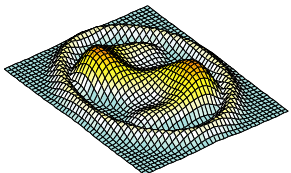
**Virtual Airspace Modeling and Simulation (VAMS)**  
**Air Transportation System Capacity-Increasing Research**  
**Technical Interchange Meeting**  
**February 10–11, 2004**



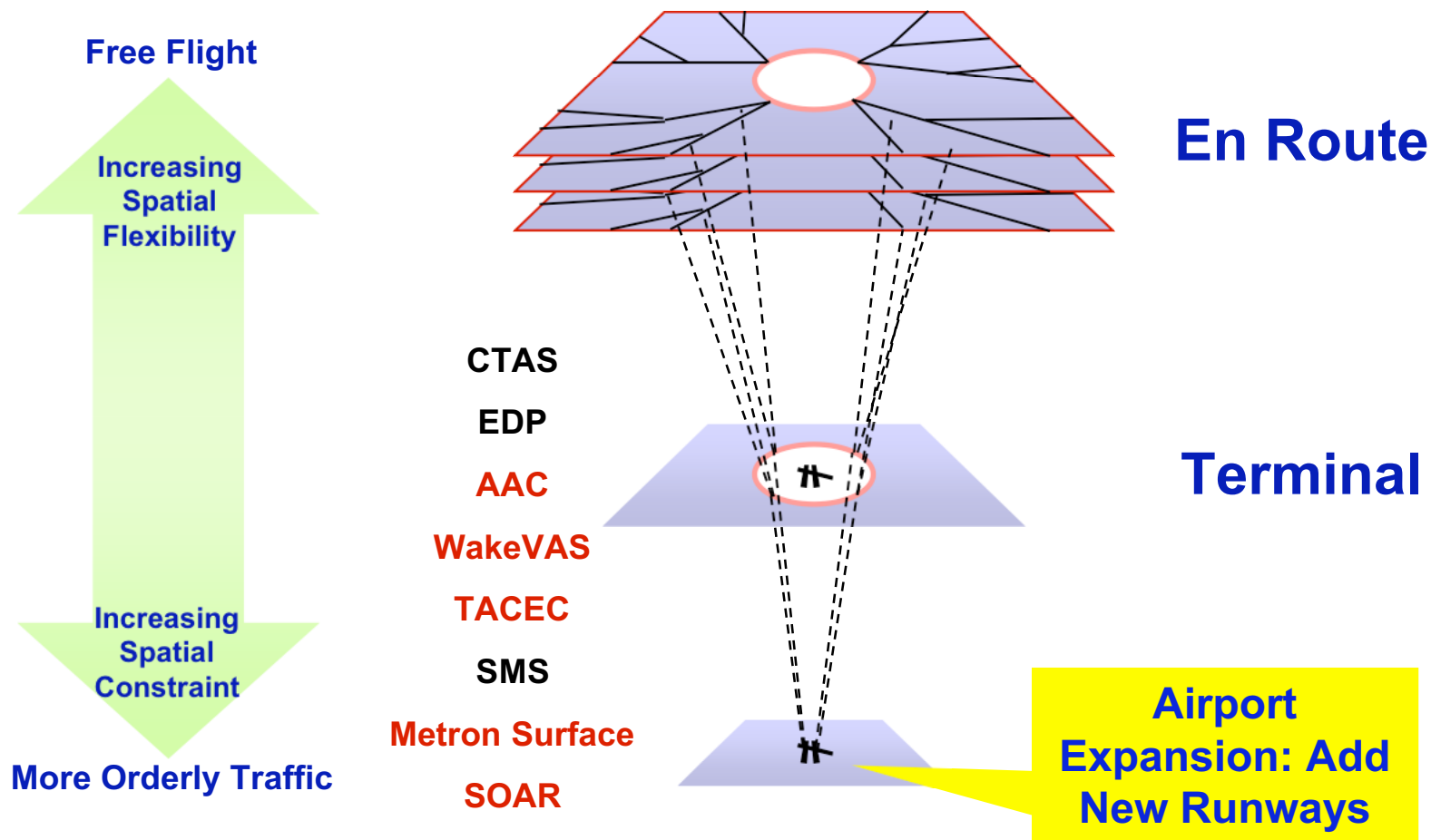
# Outline

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- Overview of SOAR concept and core ideas
- Potential benefits of SOAR
- Self-evaluation experiment design
  - Evaluation scenarios
  - Traffic demand data
  - Metrics
  - Computer simulations
- Evaluation results
- Relationship with future work
- Challenges for future analyses



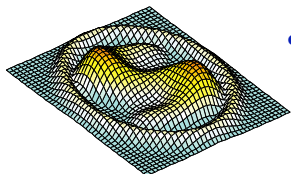
# Airspace Capacity Problem



“Traffic is concentrated at key airports

- Two-thirds of the scheduled traffic moves through hub airports
- Approximately 90% of the delay is experienced at these airports”

\_ OEP v.3.0, June 2001

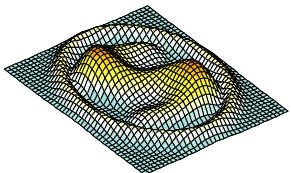


# Capacity-Related Concepts

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“The benefits that result from **capacity-related airport projects** and other initiatives will largely consist of cost savings to current and future airport users associated with **reduced time** spent in the airport system. Reduced time in system may take the form of **reduced delay, more efficient processing, or reduced idle time.**”

— **FAA Airport Benefit-Cost  
Analysis Guidance,  
December 1999**



# Examples of Activities Contributing to Taxi Delays

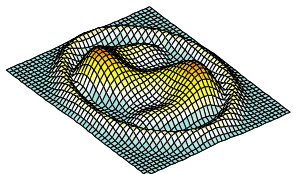
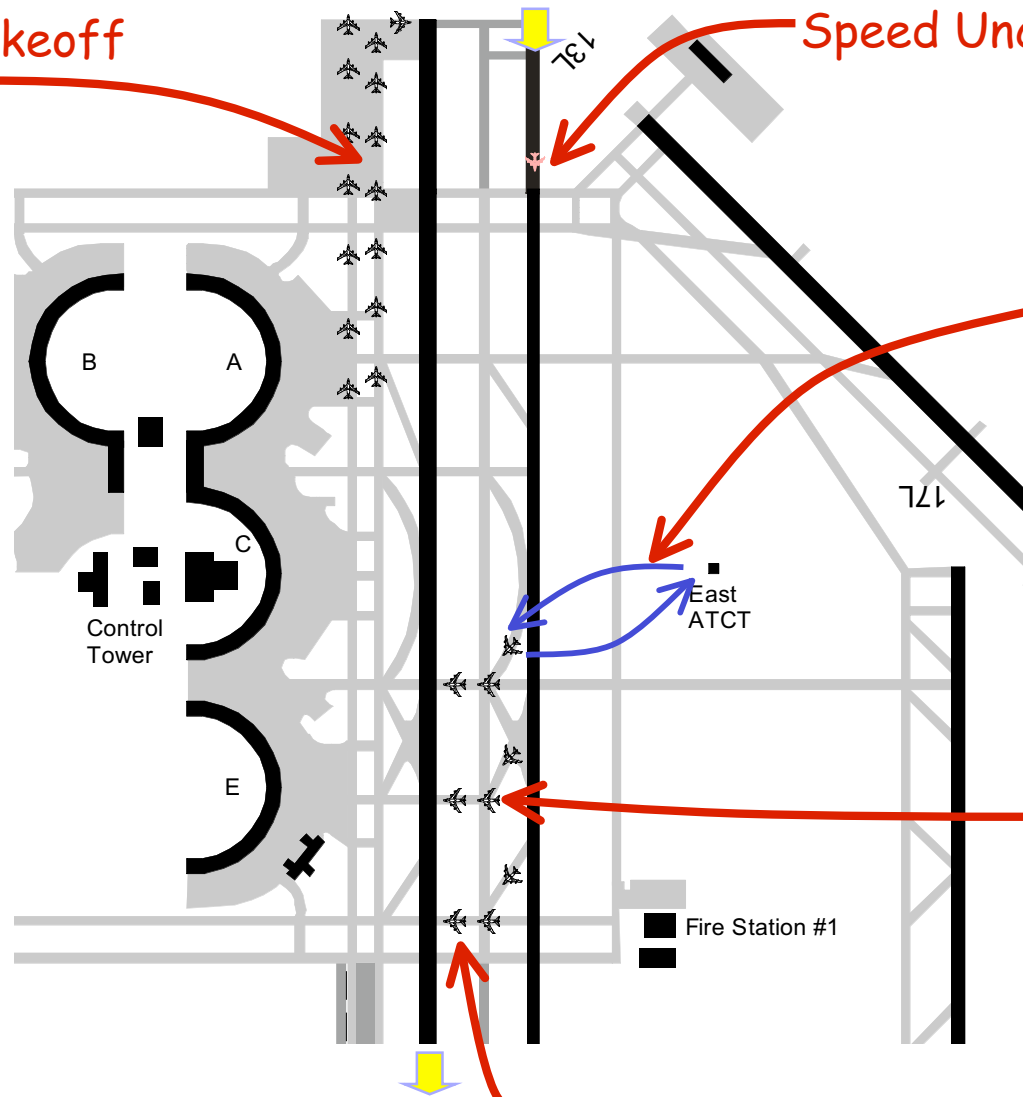
Queuing for Takeoff

Speed Uncertainty

Handoff between  
Controllers

Queuing for  
Active-Runway  
Crossing

Stop-and-Go Timing



# Core Ideas of SOAR Concept

## (I) GO-SAFE: centralized decision-making

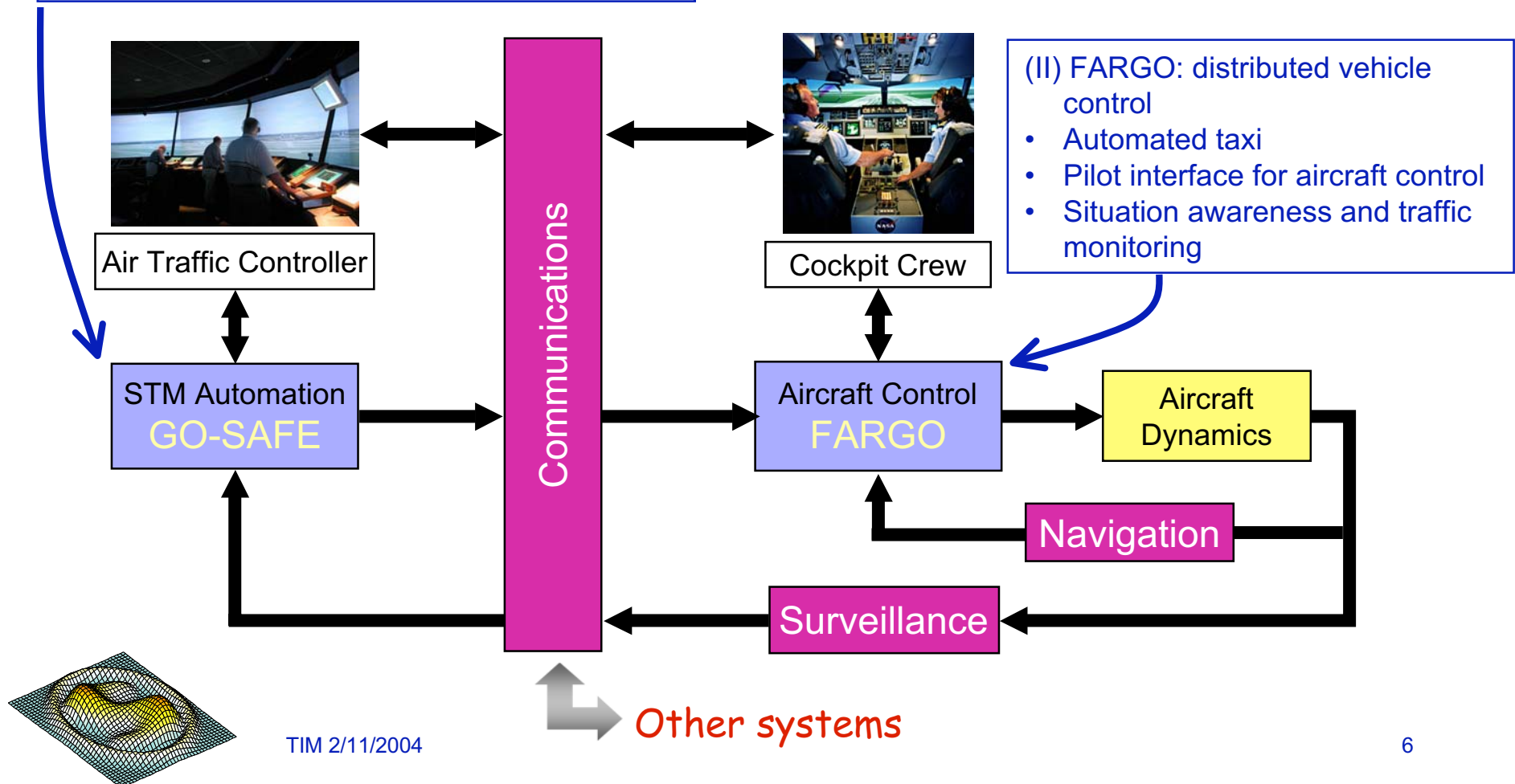
- Efficient traffic planning
- Clearance issuance and monitoring
- Situation awareness and traffic monitoring

## (III) Integrated operations

- GO-SAFE \_ FARGO
- CNS
- Information exchanges: CTAS, SMS, etc.

## (II) FARGO: distributed vehicle control

- Automated taxi
- Pilot interface for aircraft control
- Situation awareness and traffic monitoring

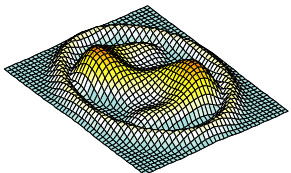


# Potential Benefits of SOAR

Improve surface capacity to accommodate capacity gain enabled by airport expansion projects and other concepts to improve arrival departure capacities .... without introducing excessive delay



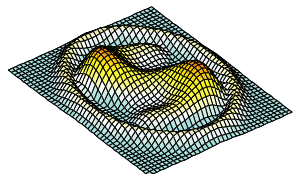
Improve surface traffic safety by enhancing situational awareness for both tower controllers and cockpit crew



# Self-Evaluation Experiment Design

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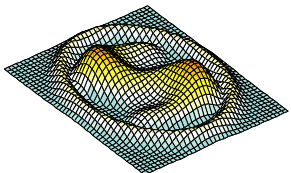
- **Key objective:** establish the benefits of the SOAR concept against current operations and procedures
- **Evaluation scenarios:**
  - Current operation procedures, roles and responsibilities
  - Variations of procedures, roles and responsibilities due to SOAR automation
- **Traffic demands:** based on LMI data sets
- **Key metrics:**
  - Achievable airport throughputs
  - Surface traffic delays
- **Computer simulations:**
  - Based on surface traffic simulation developed at OSI
  - DFW south-flow configuration with current 7 runways



# Traffic Demand Data

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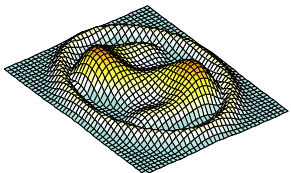
- **Bases on LMI data sets**
  - 250 airports (May 17, 2002): extracted from ETMS
  - 98 airports: filtered from 250-airport data
  - Future: transportation demand and economic analysis forecast for 2022, for 98 airports
- **Data filtered for DFW operations**
  - Departure traffic: departure schedules as specified in data set
  - Arrival traffic: arrival schedules determined based on departure schedules from originating airports and travel time
- **Assignment of runways defined as part of traffic data preprocessing**



# Reference Traffic Data

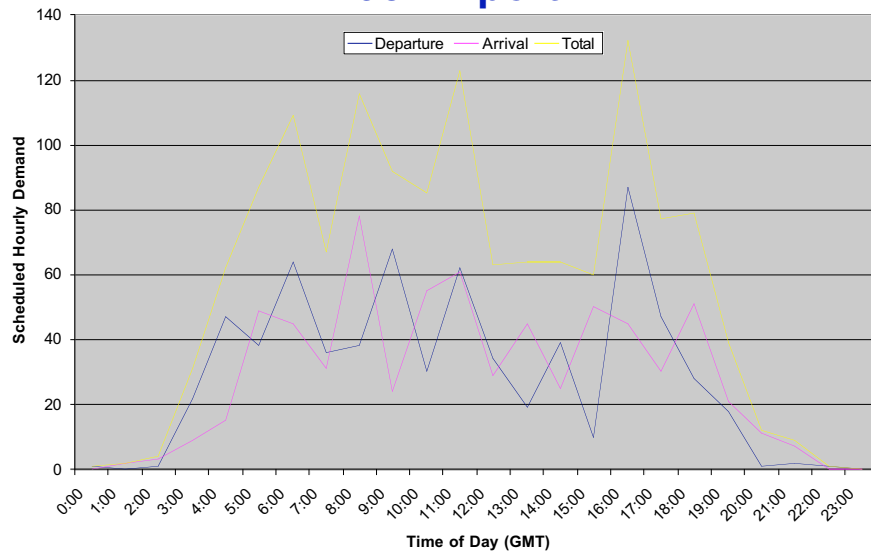
- **Aviation System Performance Metrics (ASPM)**
- **Sources:**
  - Enhanced Traffic Management System (ETMS)
  - ARINC Out, Off, On and In (OOOI)
- **DFW South-Flow Configuration**
  - 4 arrival runways, 3 departure runways
  - Optimum rate ~ 40 op/hr or 1.5 min/op

	Hourly Rates			15-min Rates		
	Departure	Arrival	Total	Departure	Arrival	Total
Optimum	120	150	270	30	38	68
Reduced	90	95	185	23	24	46

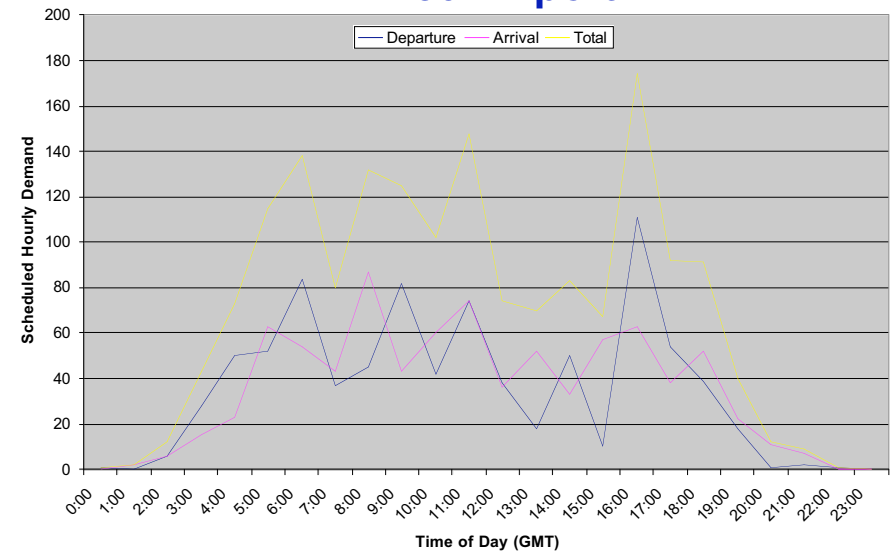


# Traffic Demand Data

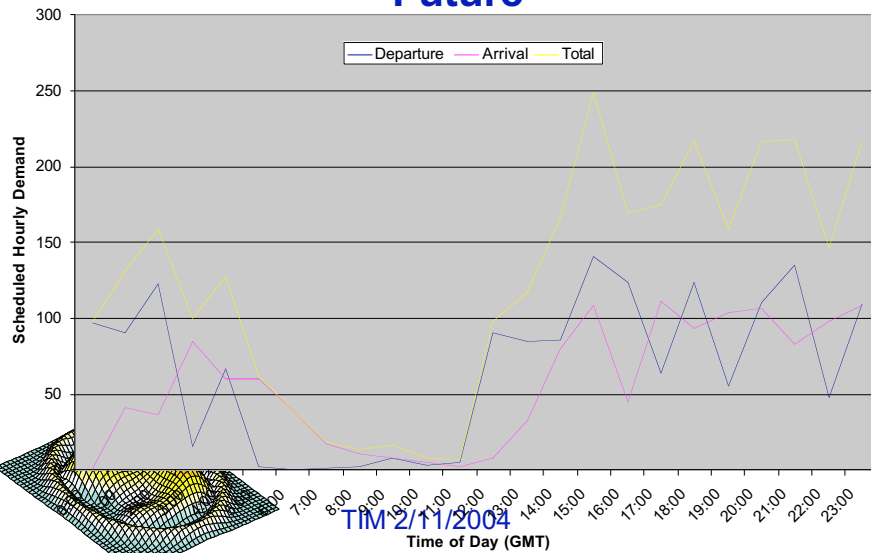
## 98-Airport



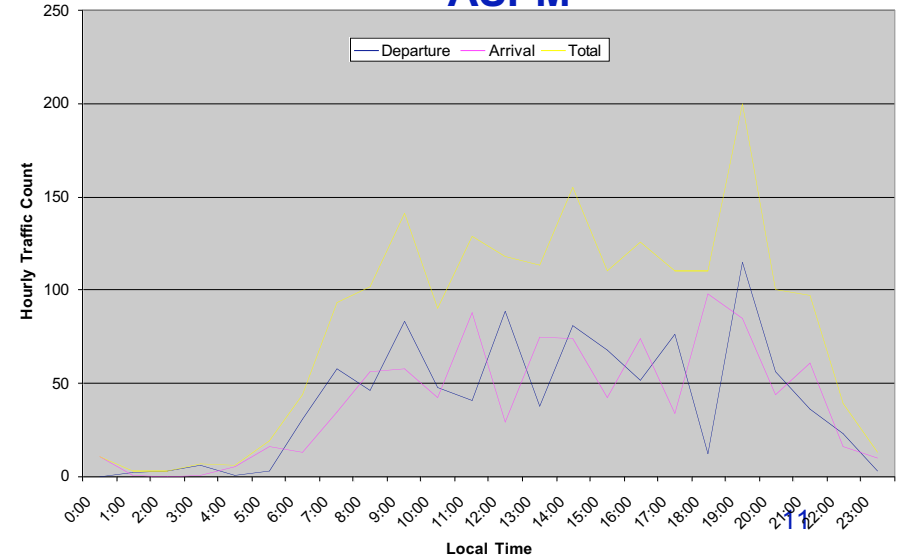
## 250-Airport



## Future



## ASPM



## Metrics

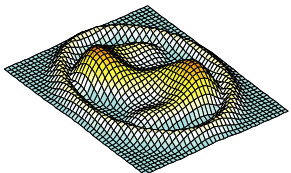
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- **Airport Periphery Capacity: Arrival/Departure Throughputs**
- **Surface Capacity: Taxi Delay/Efficiency**

$$\text{Taxi Delay} = \text{Actual Taxi Time} - \text{Unimpeded Taxi Time} \geq 0$$

$$\begin{aligned}\text{Taxi Efficiency} &= \frac{\text{Unimpeded Taxi Time}}{\text{Actual Taxi Time}} \\ &= \frac{\text{Actual Effective Speed}}{\text{Unimpeded Effective Speed}} \leq 1\end{aligned}$$

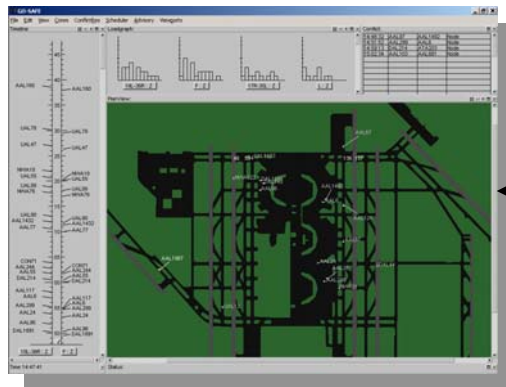
$$\text{Surface Traffic Efficiency} = \frac{\sum \text{Unimpeded Taxi Time}}{\sum \text{Actual Taxi Time}}$$



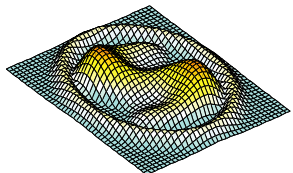
# Adaptation of Computer Simulation for Evaluation

**SOAR**

**GO-SAFE GUI**



**Current  
Operation**



TIM 2/11/2004

Time-based conflict-free routes on taxiways and runways

**GO-SAFE**

Runway Scheduler

Route Manager

Clearance Manager

Conflict Resolution

FARGO delivers route-tracking performance

**GO-Sim**

ATC

Flight Control

Time information removed from routes

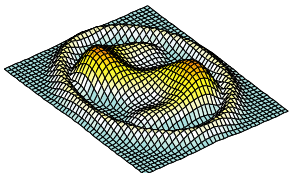
ATC controls runway usage responding to traffic

Flight controlled by taxi speed

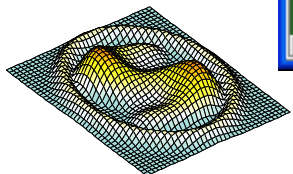
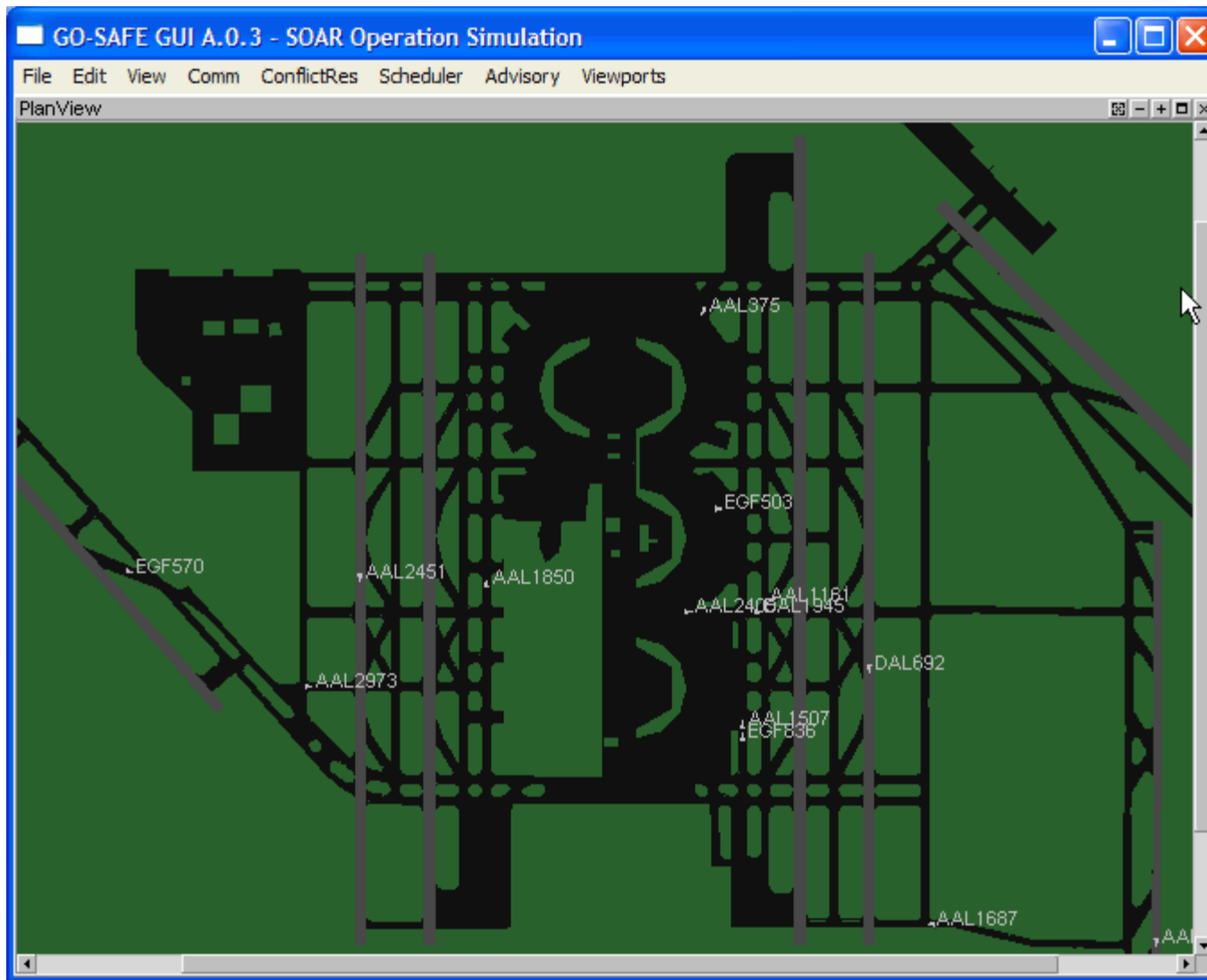
# Evaluation Results

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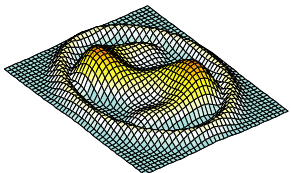
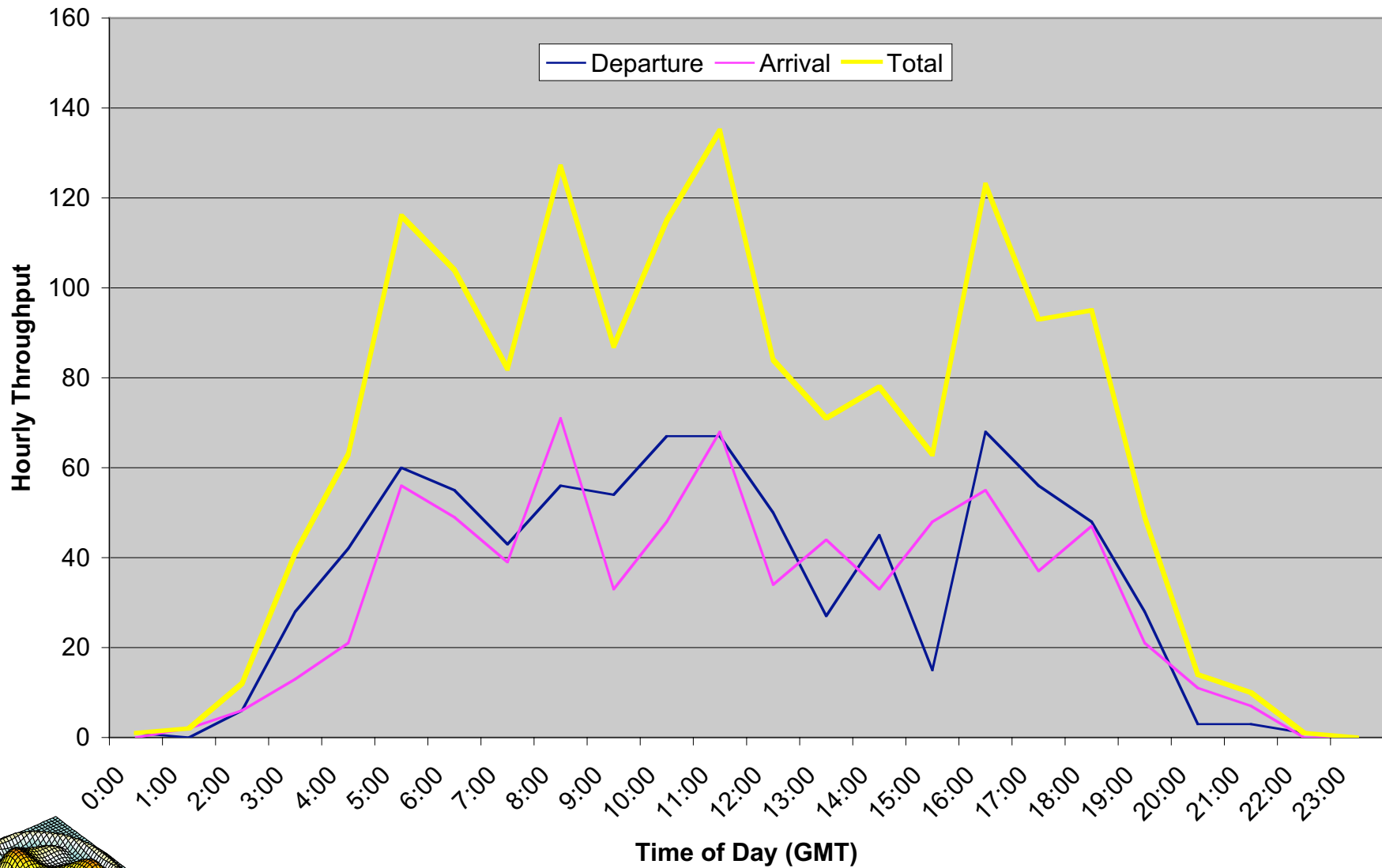
- **Discussion limited to two demand sets**
  - 250-airport set represents current demand
  - Future demand set
- **No assumption on increased runways and reduced separation**
- **Capacity-related metrics considered in two areas:**
  - Airport periphery: runway throughputs
  - Airport surface: taxi delay and efficiency



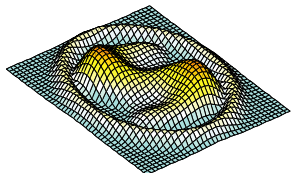
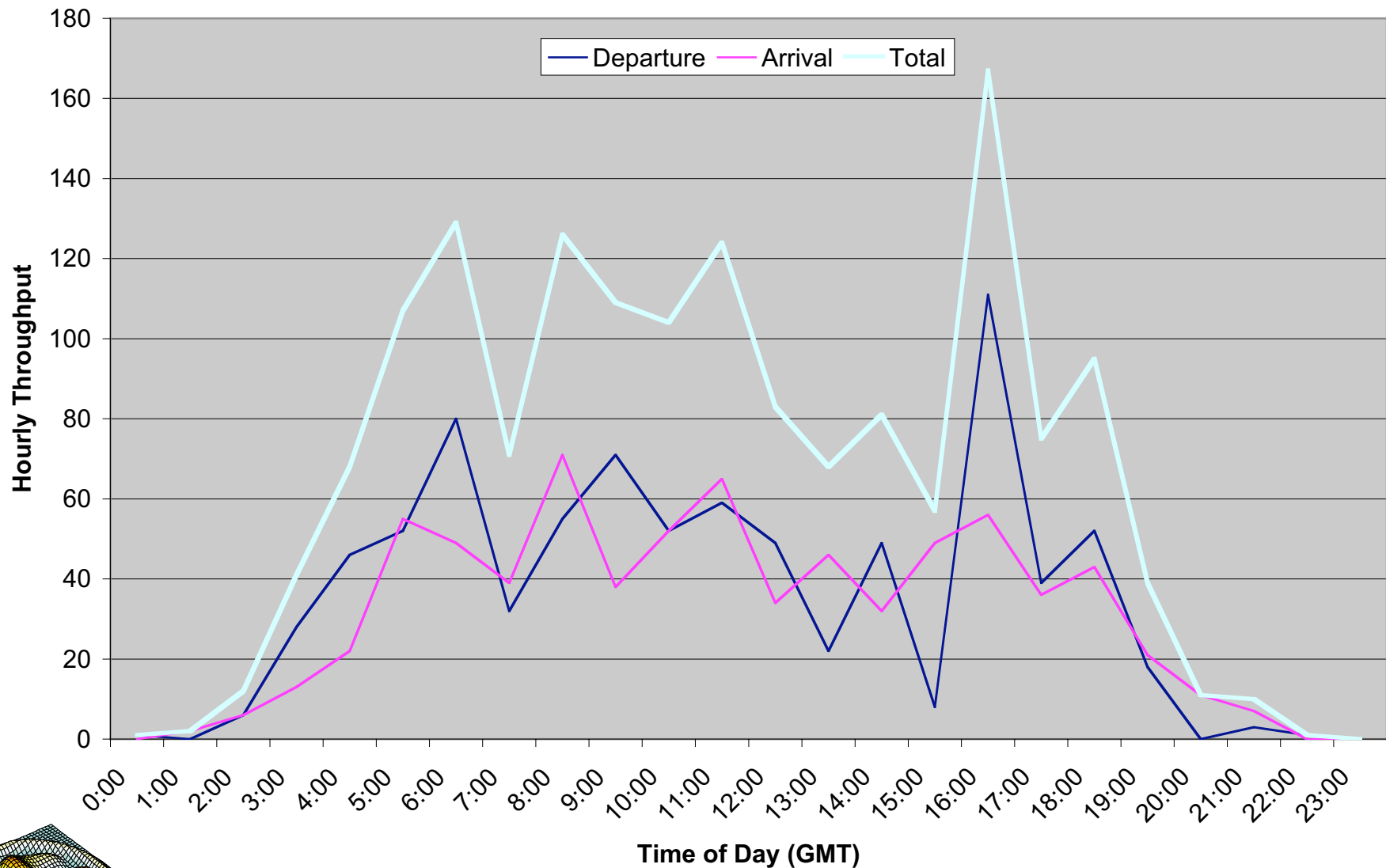
# Simulation Example



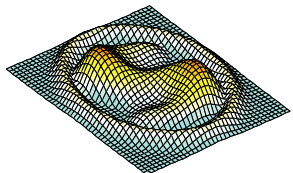
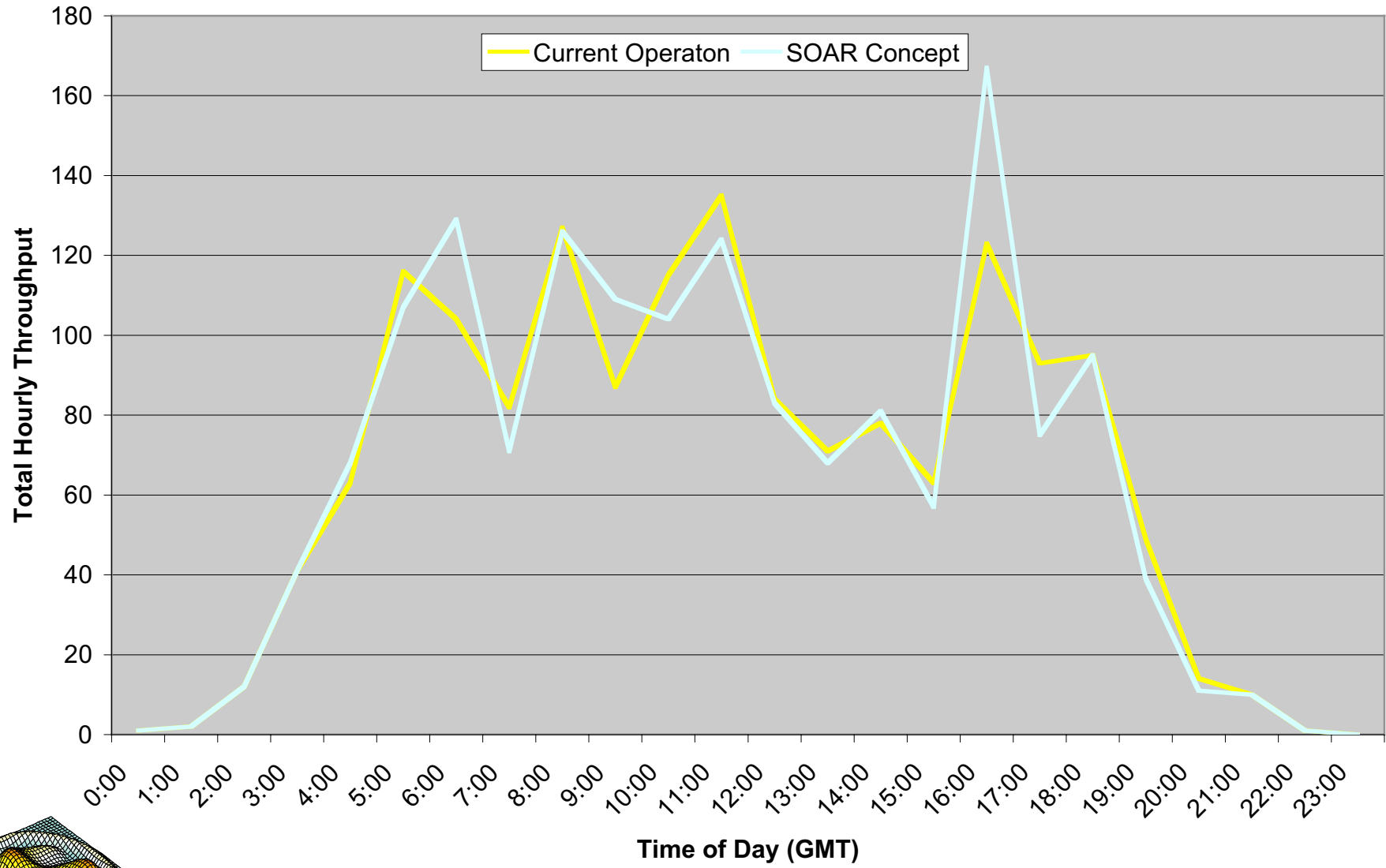
# Hourly Throughputs with Current Operations for 250-Airport Demand Set



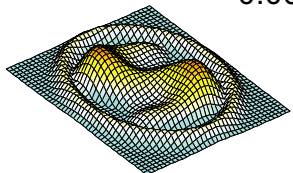
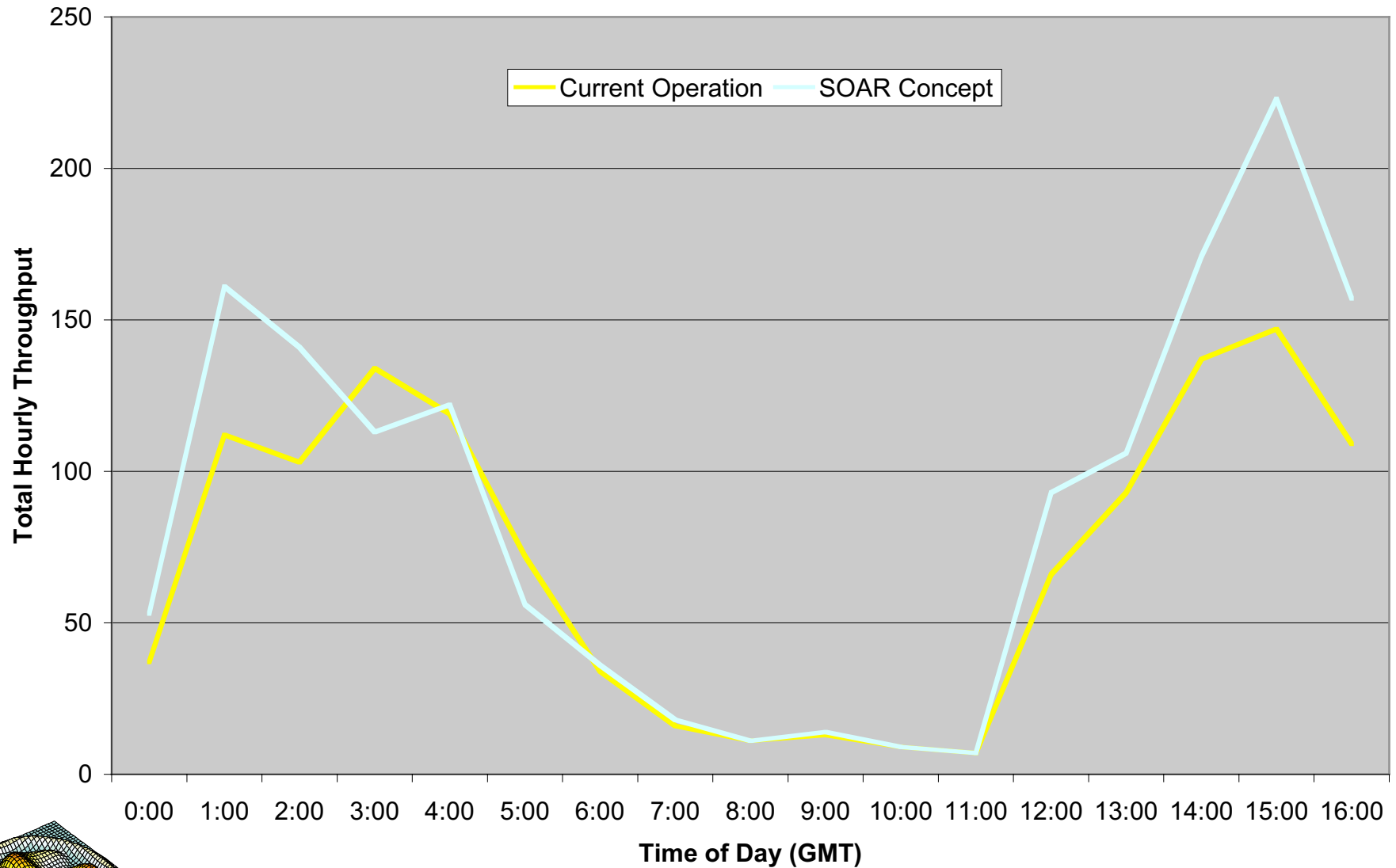
# Hourly Throughputs with SOAR Concept for 250-Airport Demand Set



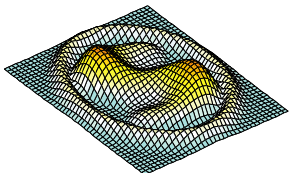
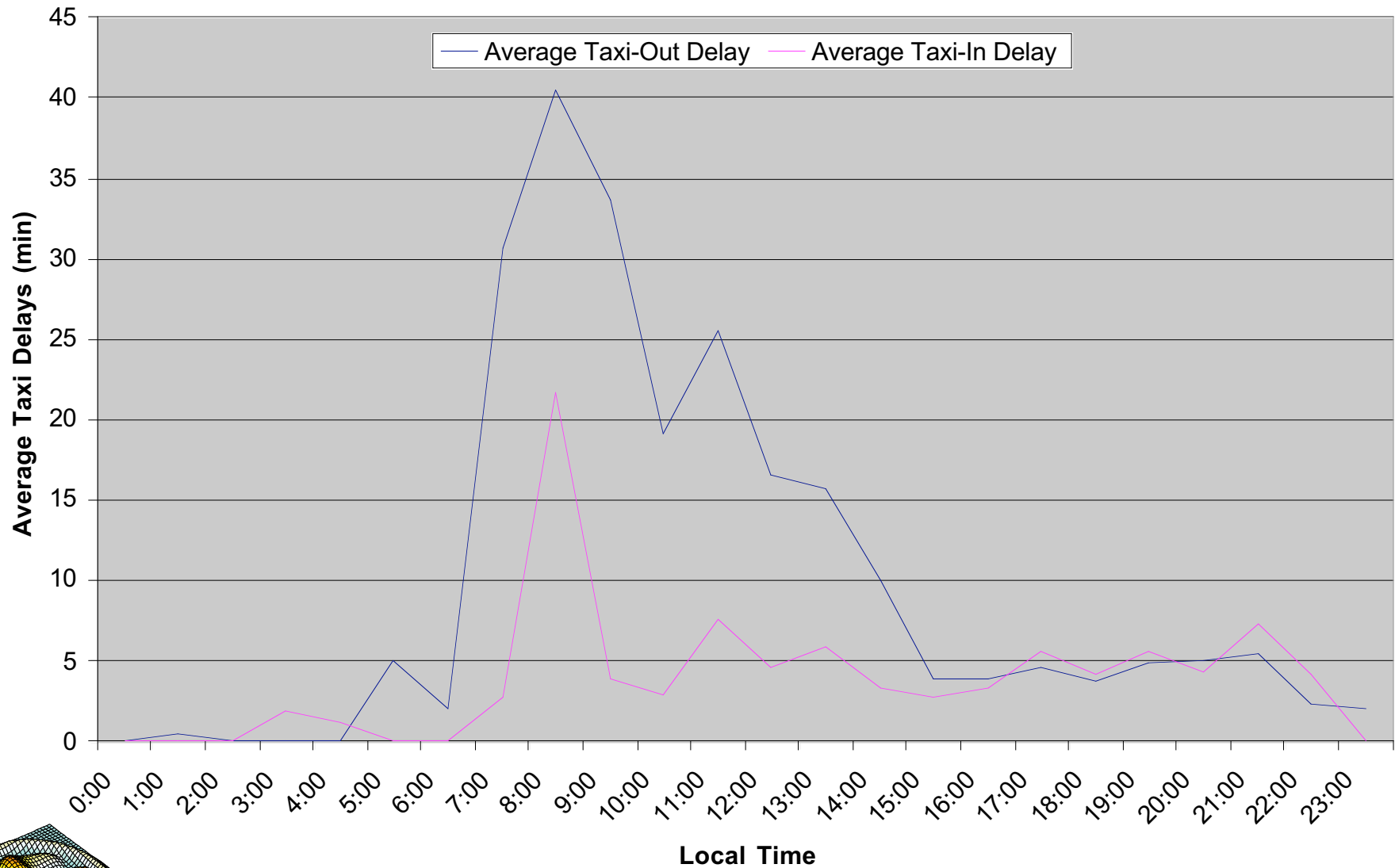
# Comparison of Hourly Throughputs for 250-Airport Demand Set: Current Ops vs SOAR Concept



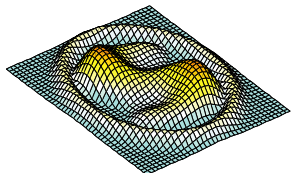
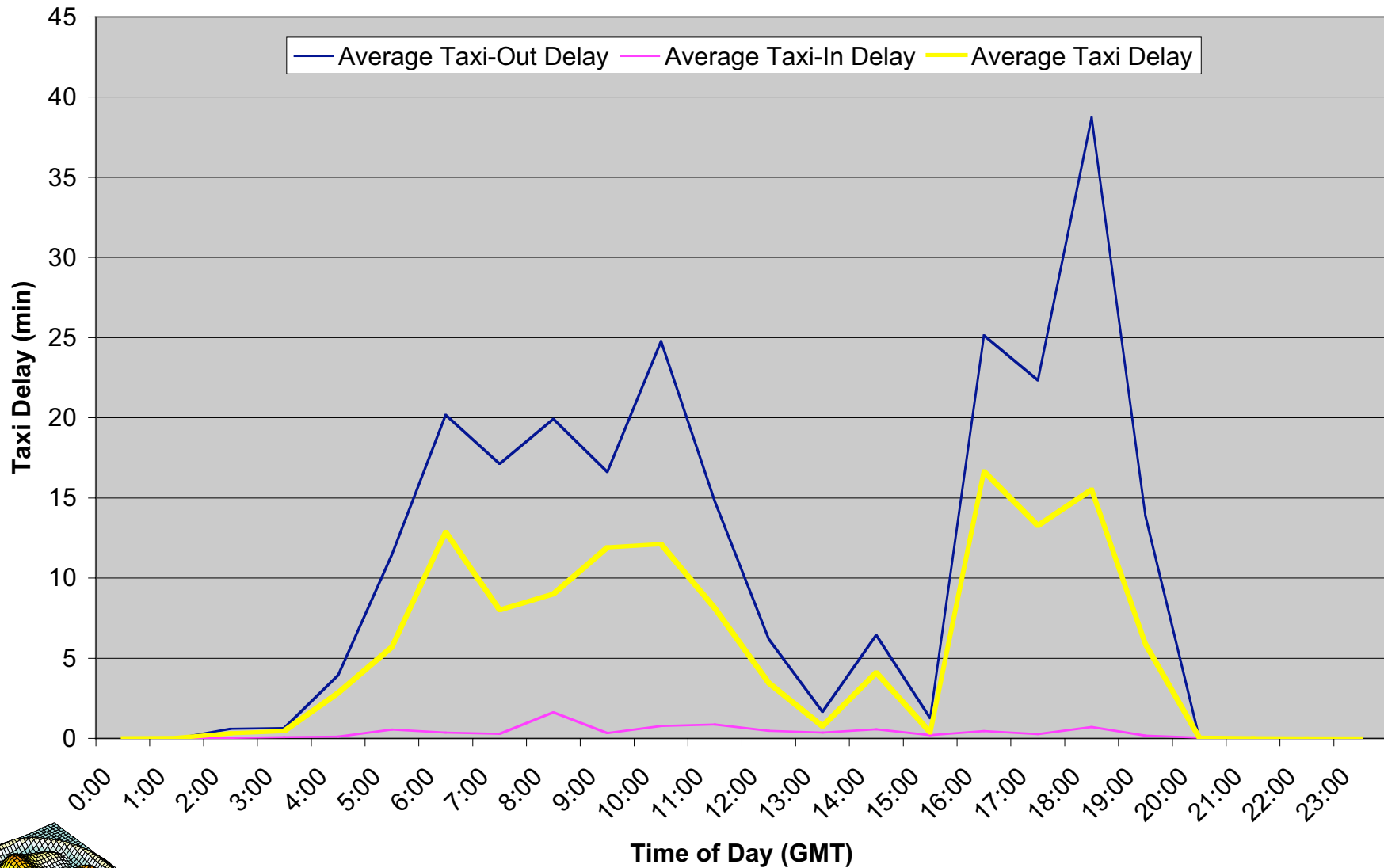
# Comparison of Hourly Throughputs for Future Demand Set: Current Ops vs SOAR Concept



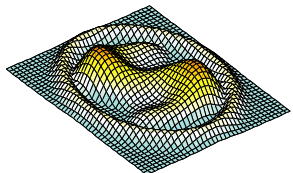
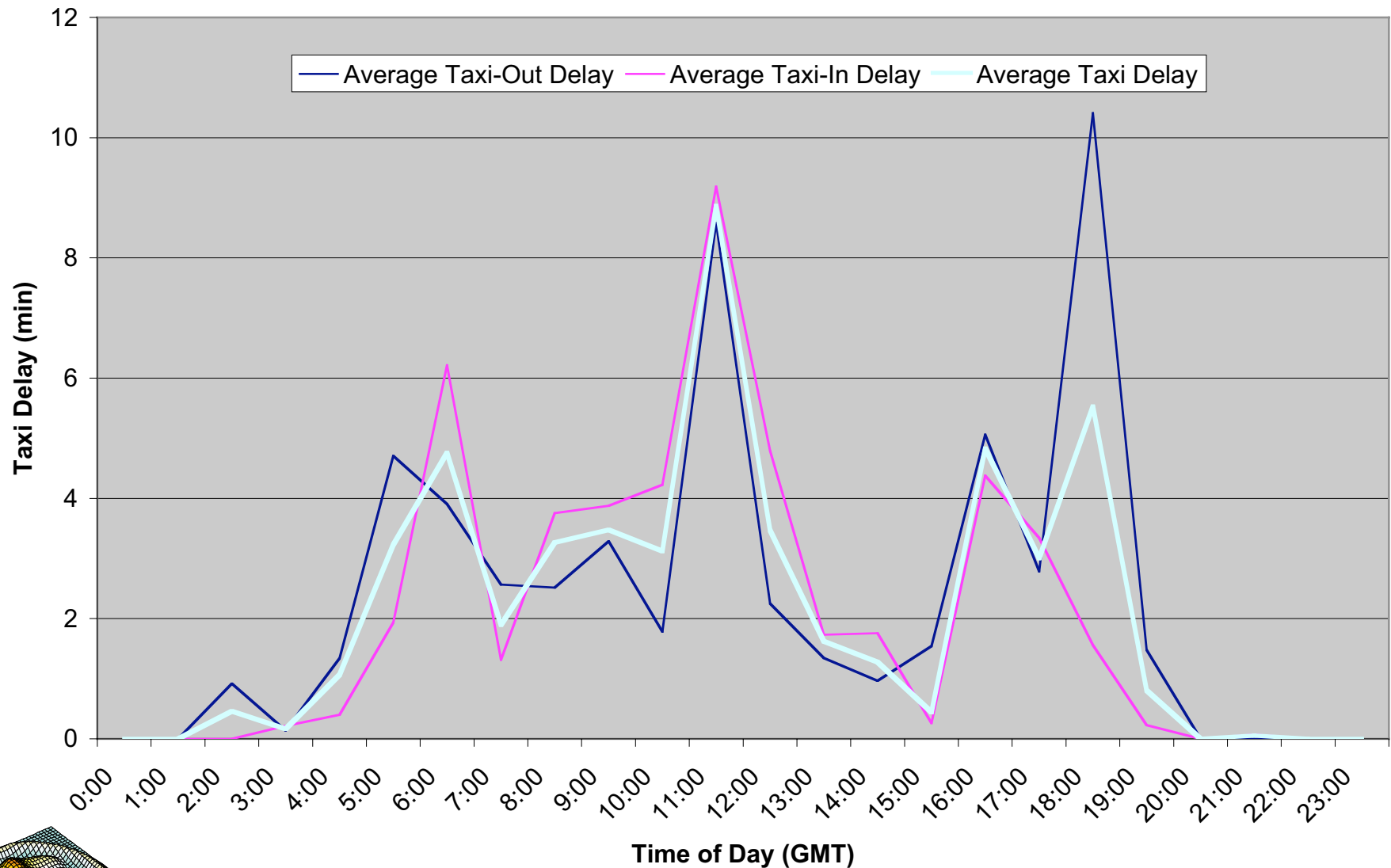
# Average Taxi Delays from ASPM



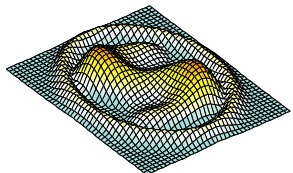
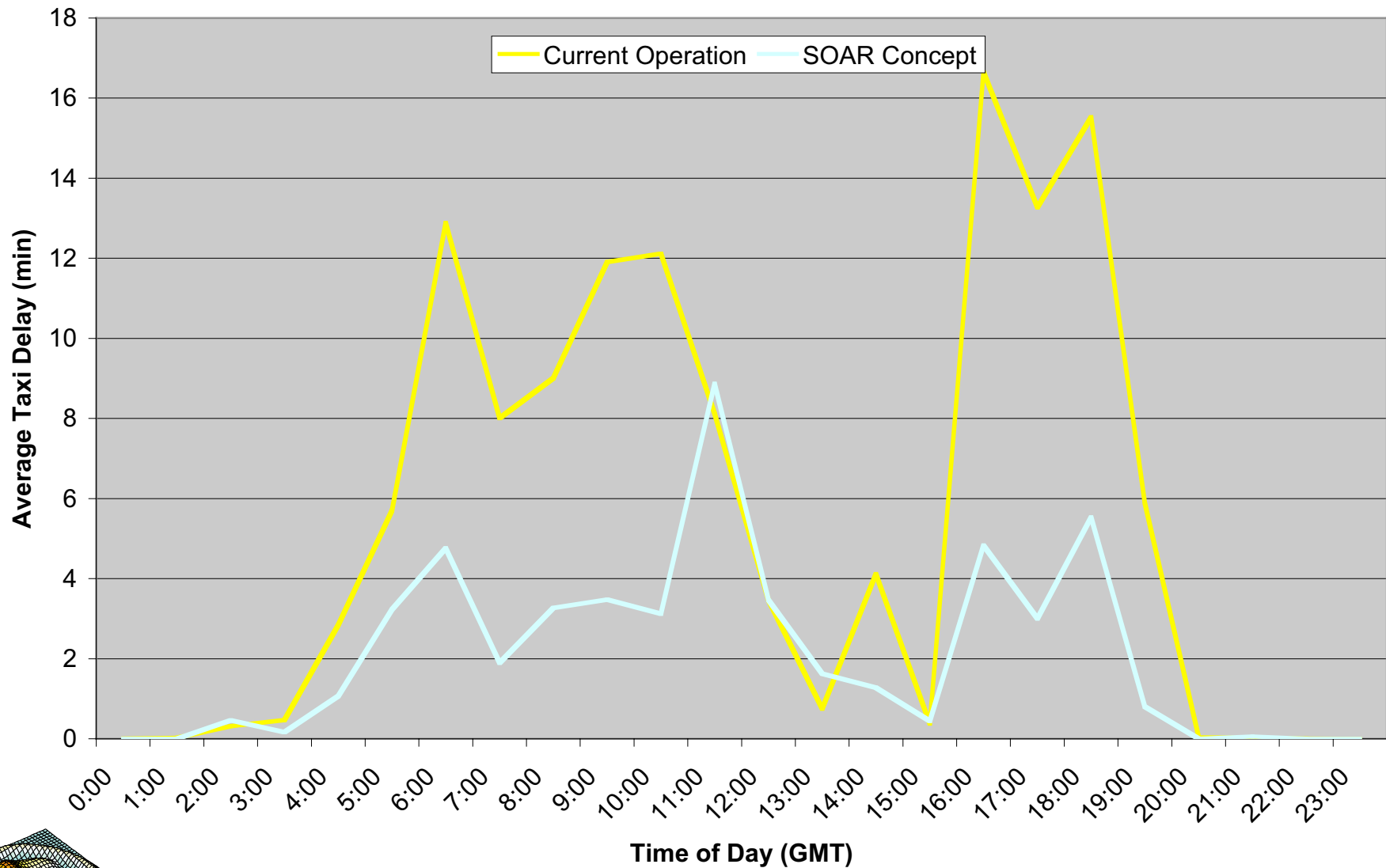
# Average Taxi Delays with Current Operations for 250-Airport Demand Set



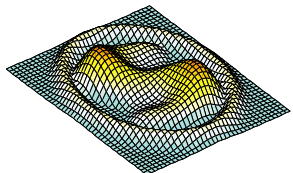
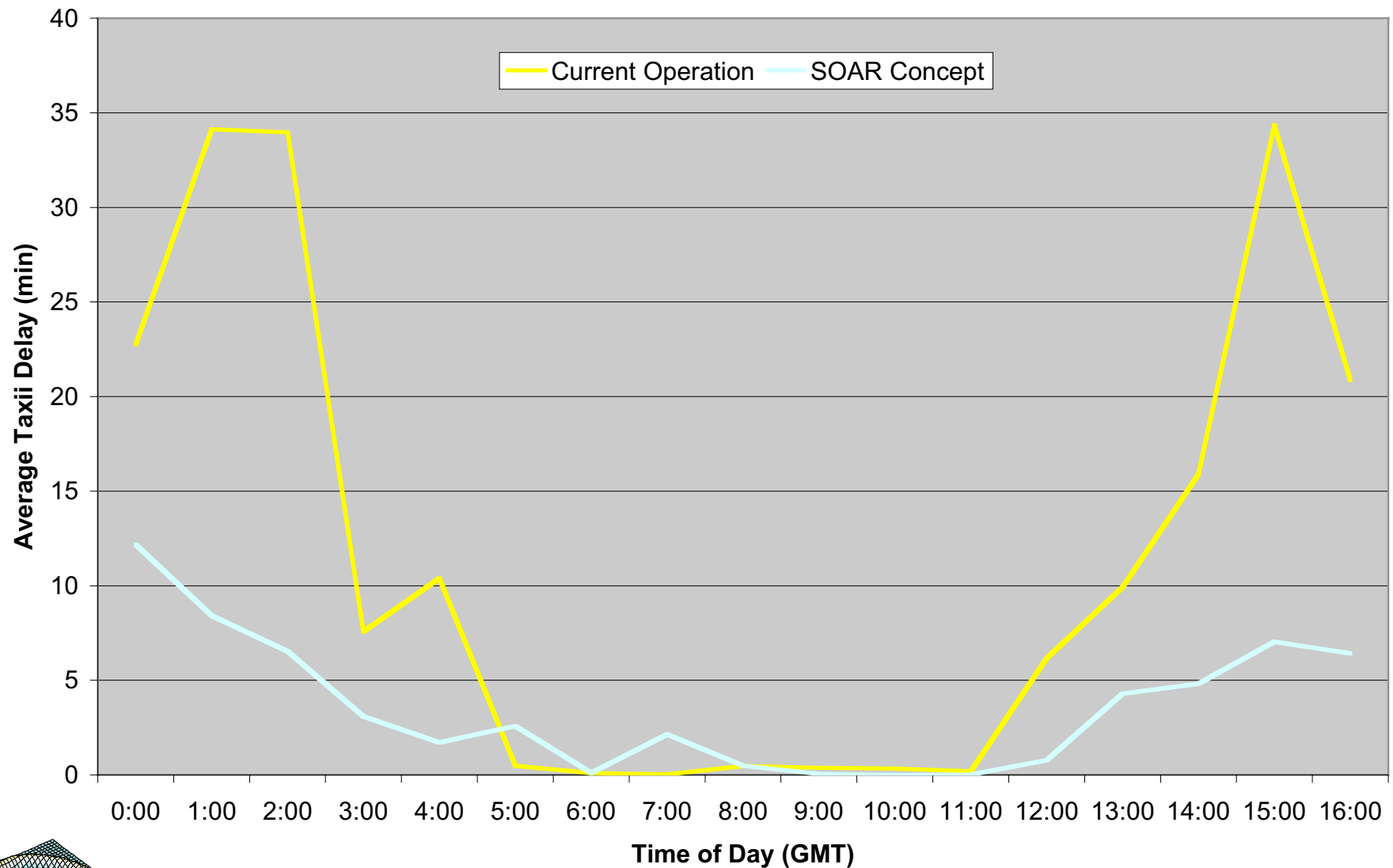
# Average Taxi Delays with SOAR Concept for 250-Airport Demand Set



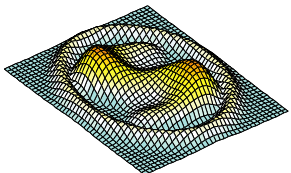
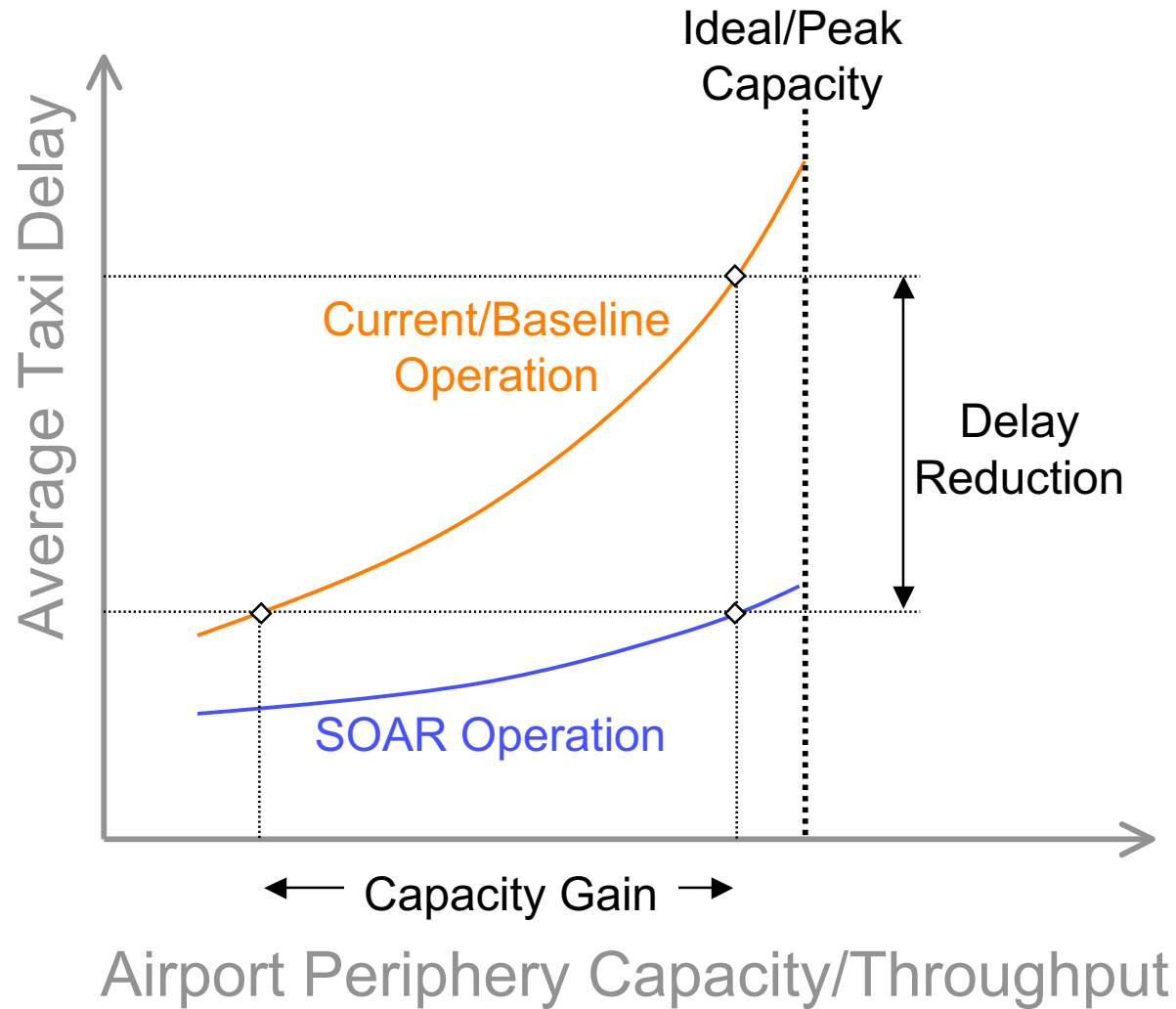
# Comparison of Average Taxi Delays for 250-Airport Demand Set: Current Ops vs SOAR Concept



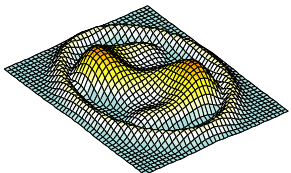
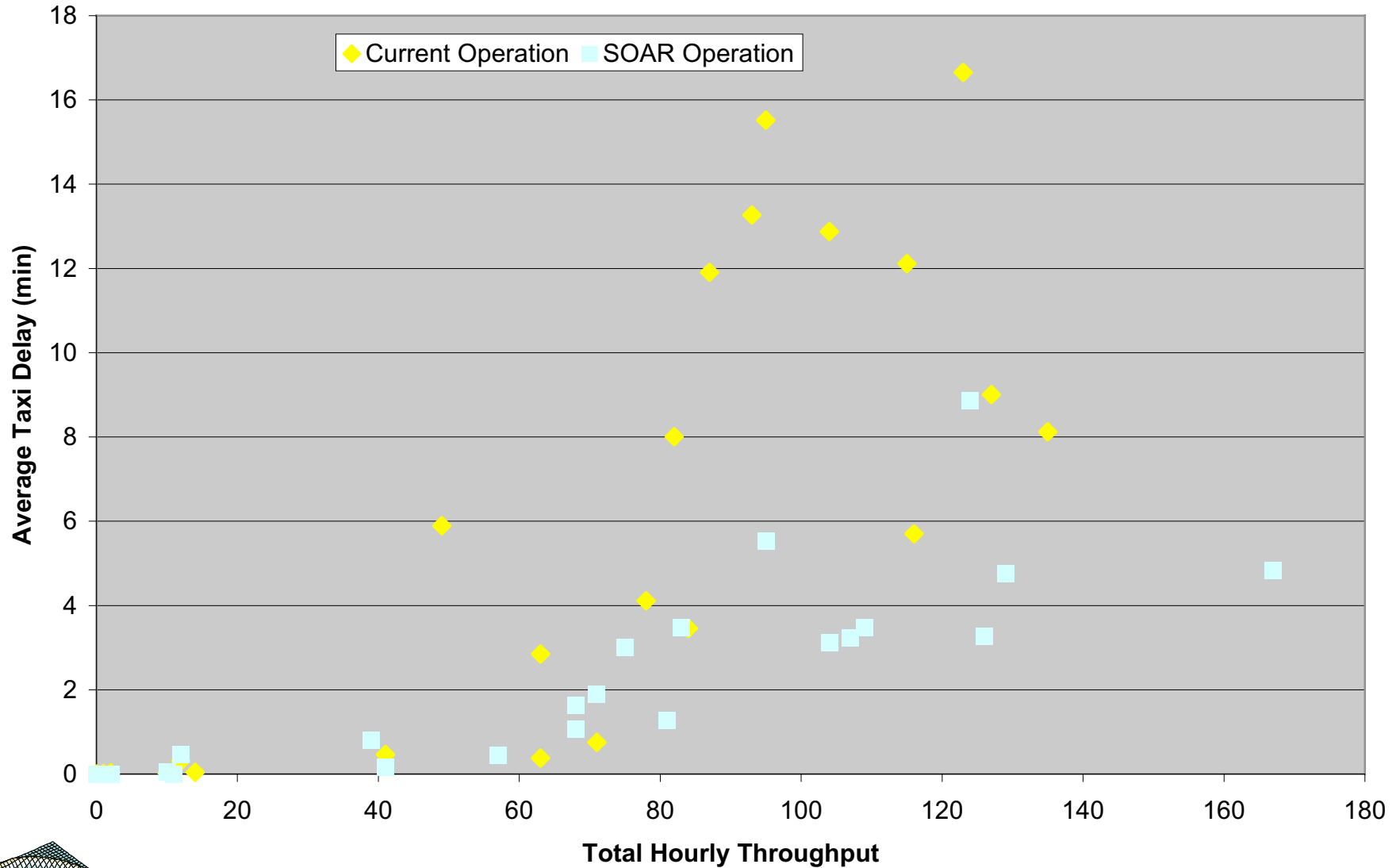
# Comparison of Average Taxi Delays for Future Demand Set: Current Ops vs SOAR Concept



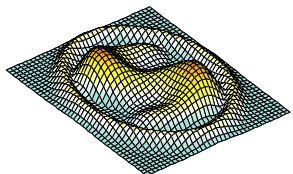
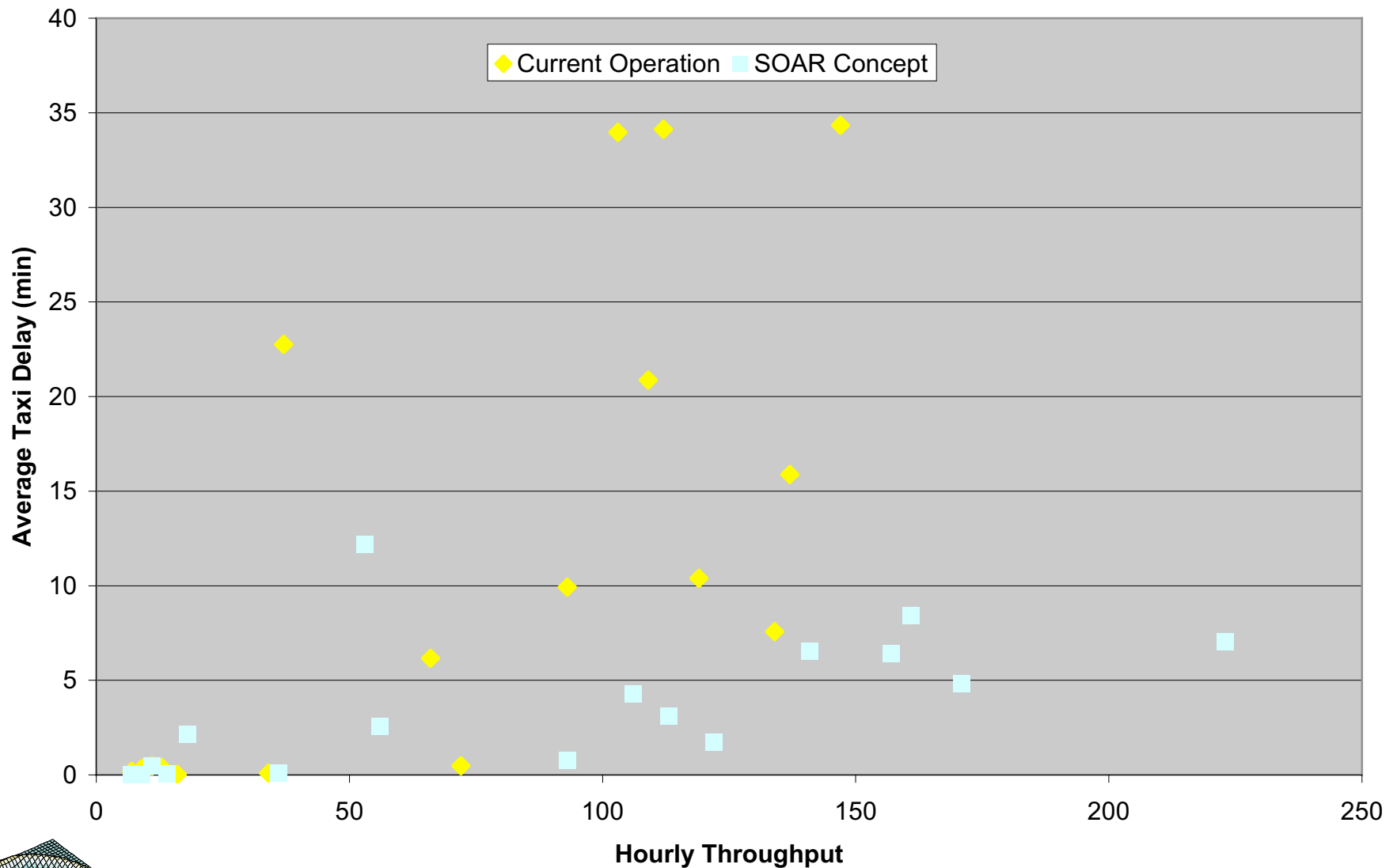
# Anticipated SOAR Benefits of Capacity Gain and Delay Reduction



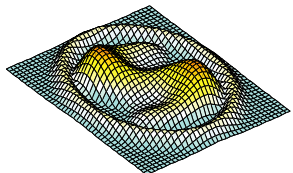
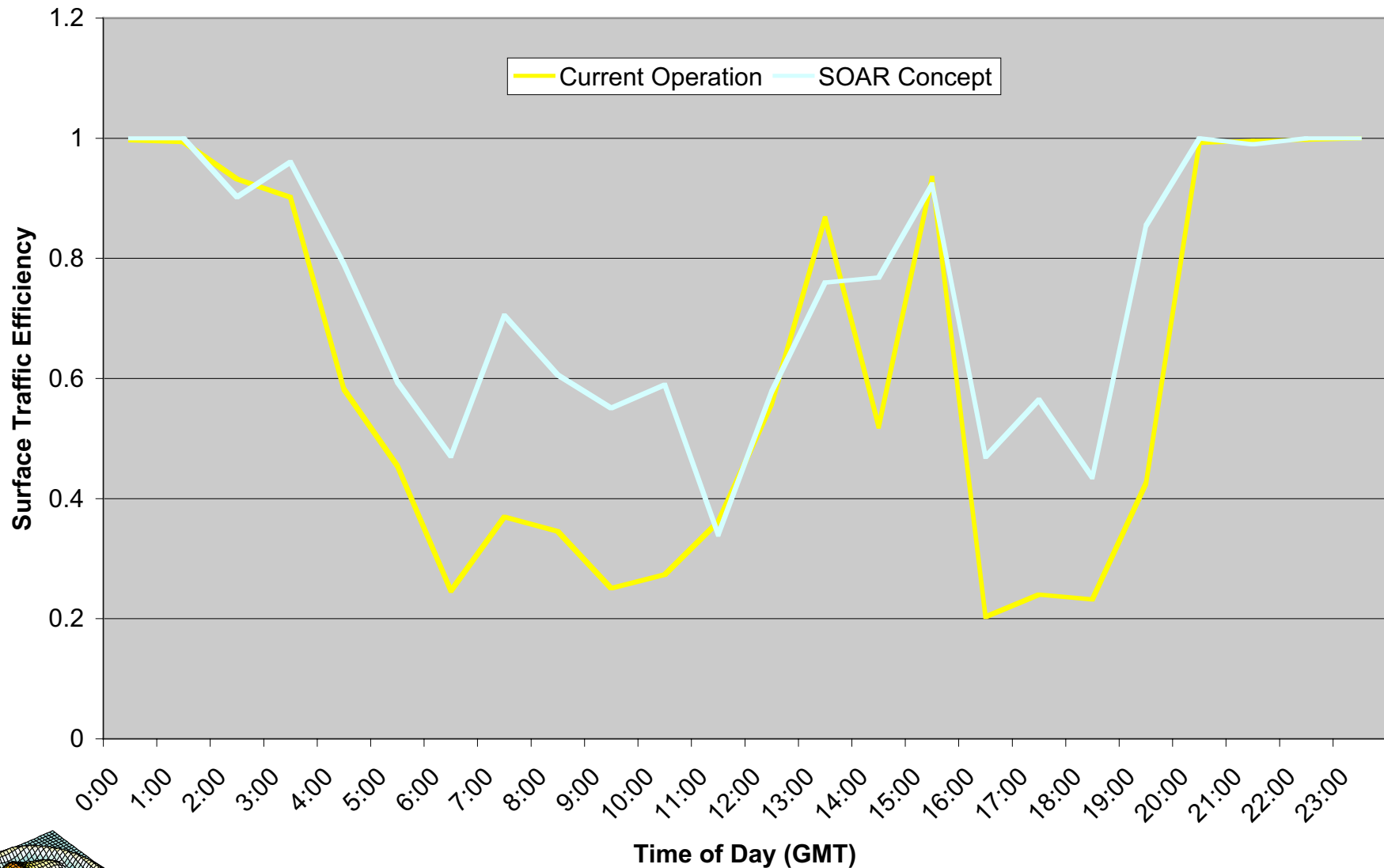
# Relationship between Taxi Delay and Throughput for 250-Airport Demand Set: Current Ops vs SOAR



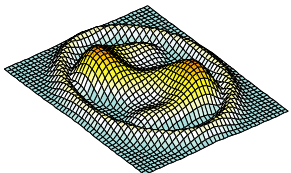
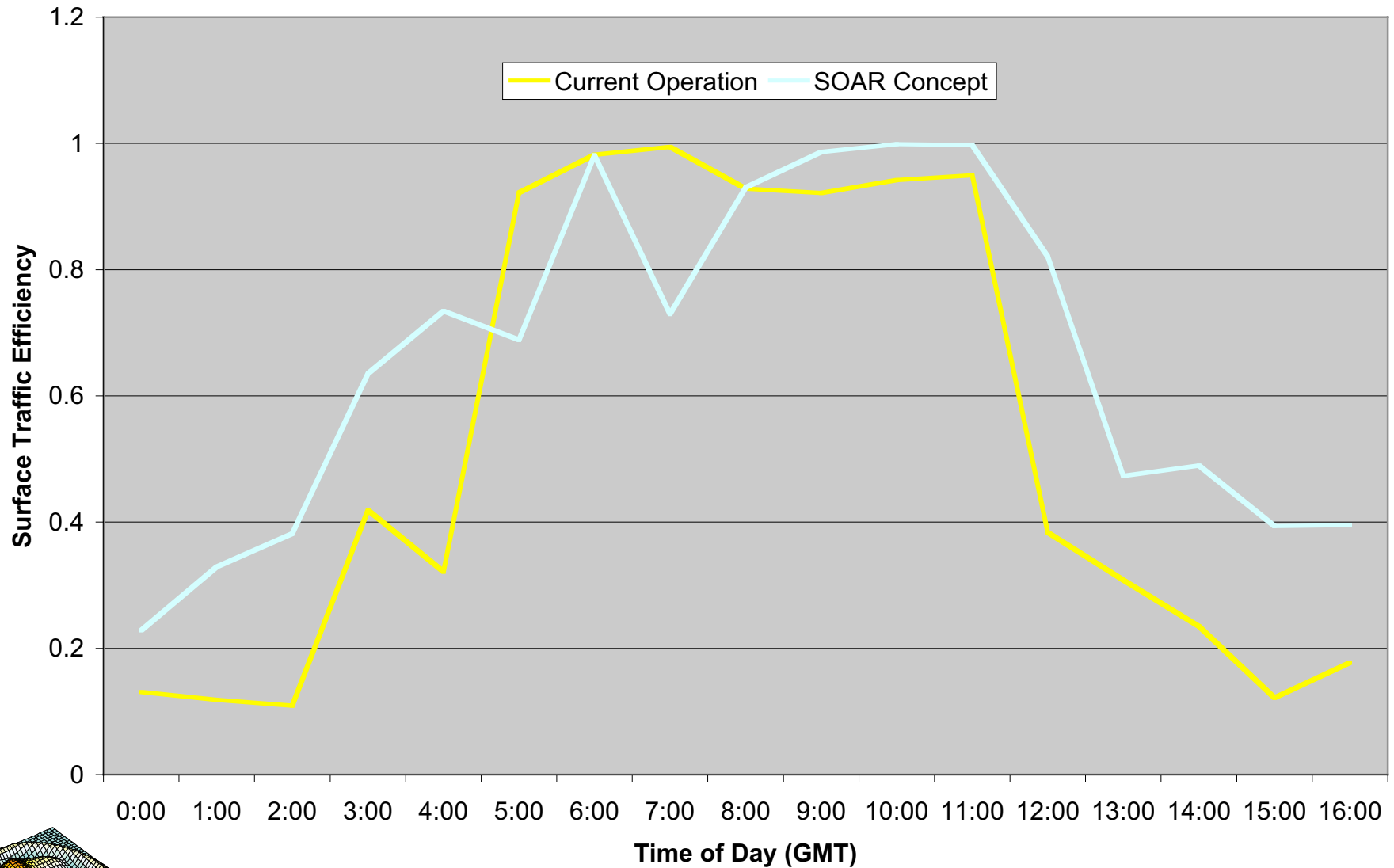
# Relationship between Taxi Delay and Throughput for Future Demand Set: Current Ops vs SOAR



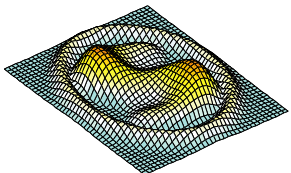
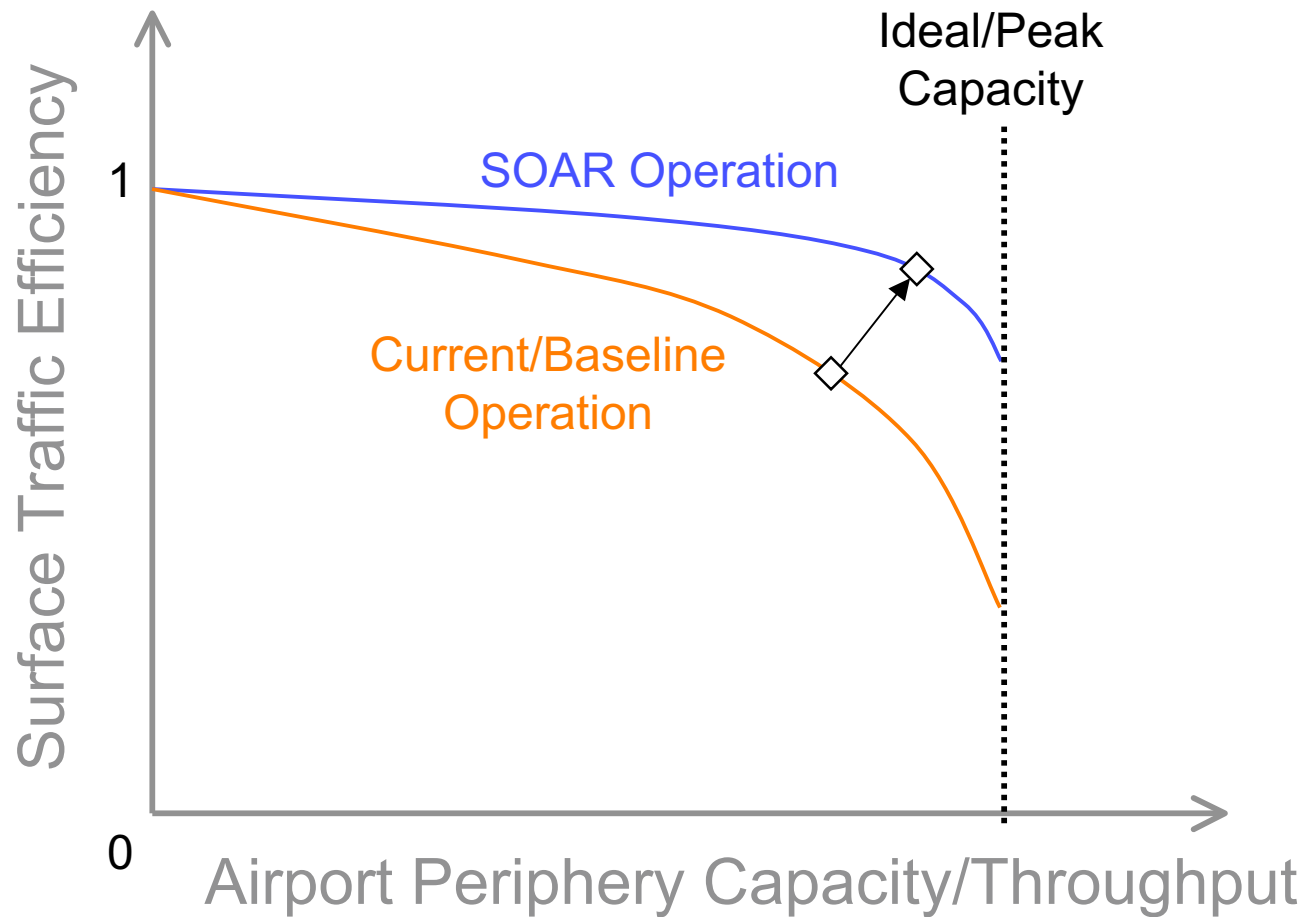
# Comparison of Surface Traffic Efficiencies for 250-Airport Demand Set: Current Ops vs SOAR Concept



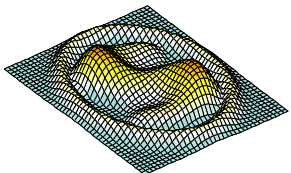
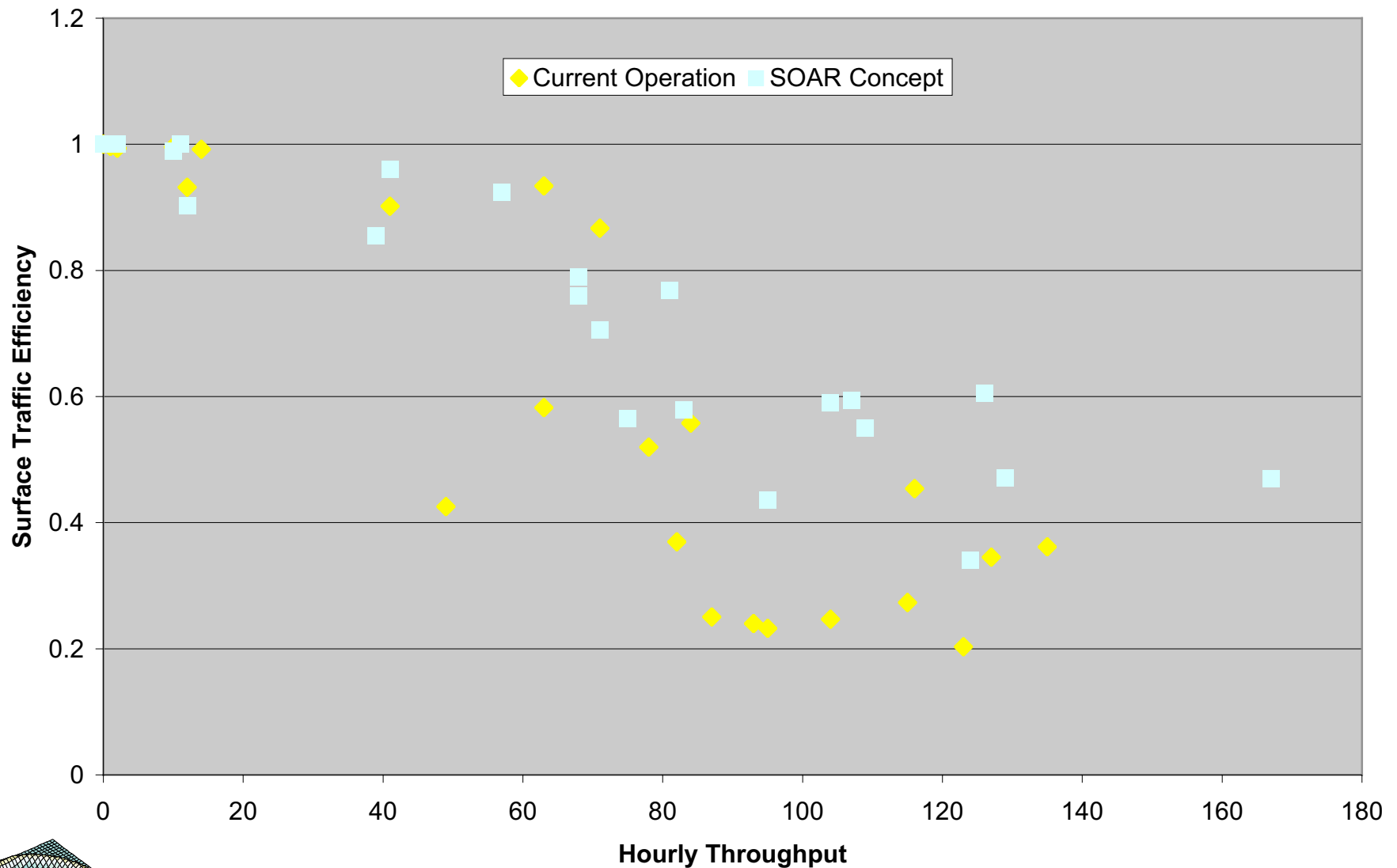
# Comparison of Surface Traffic Efficiencies for Future Demand Set: Current Ops vs SOAR Concept



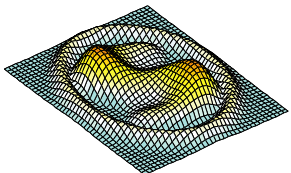
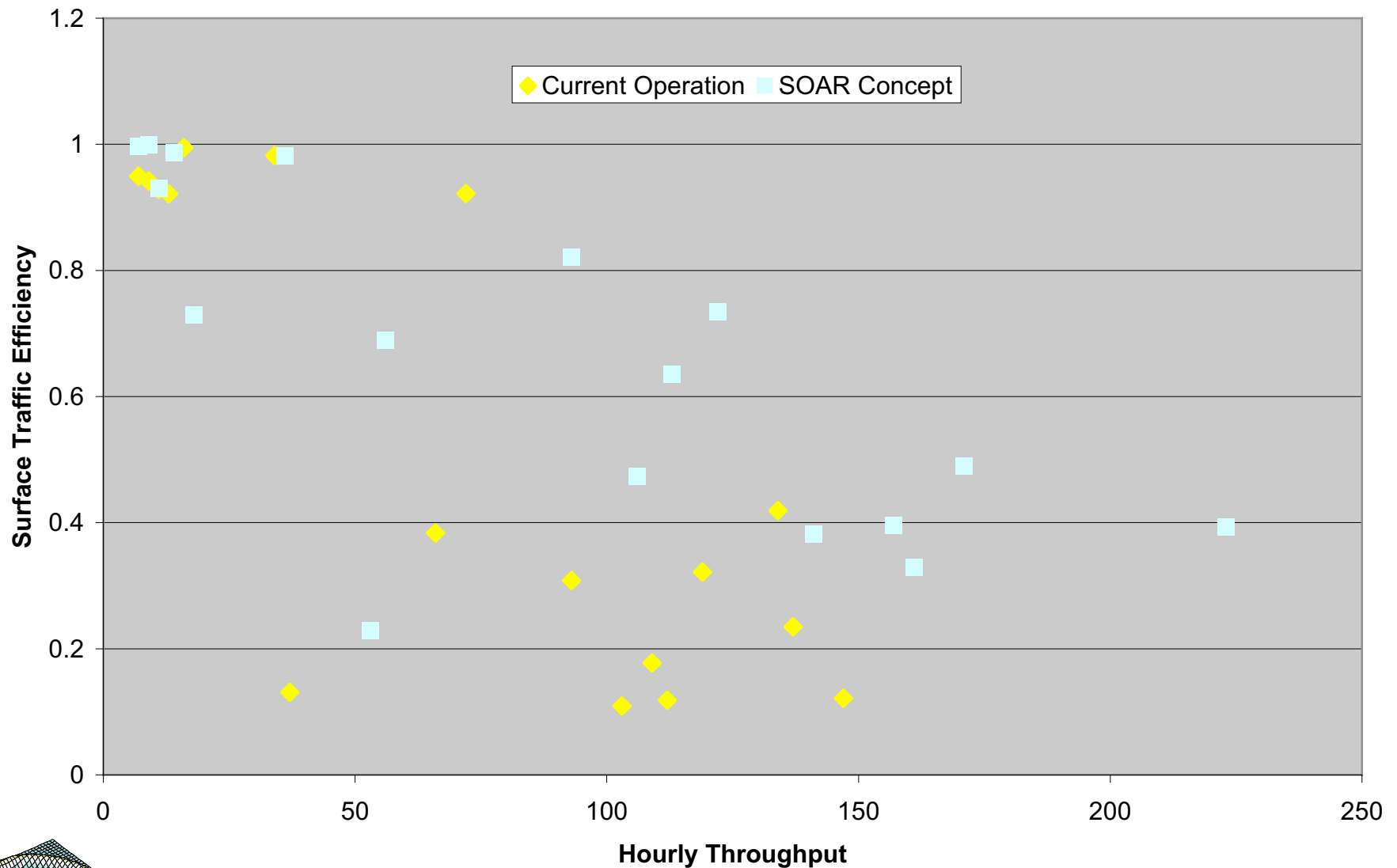
# Anticipated Improvement in Efficiency/Capacity Tradeoff



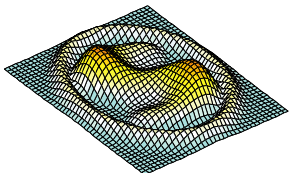
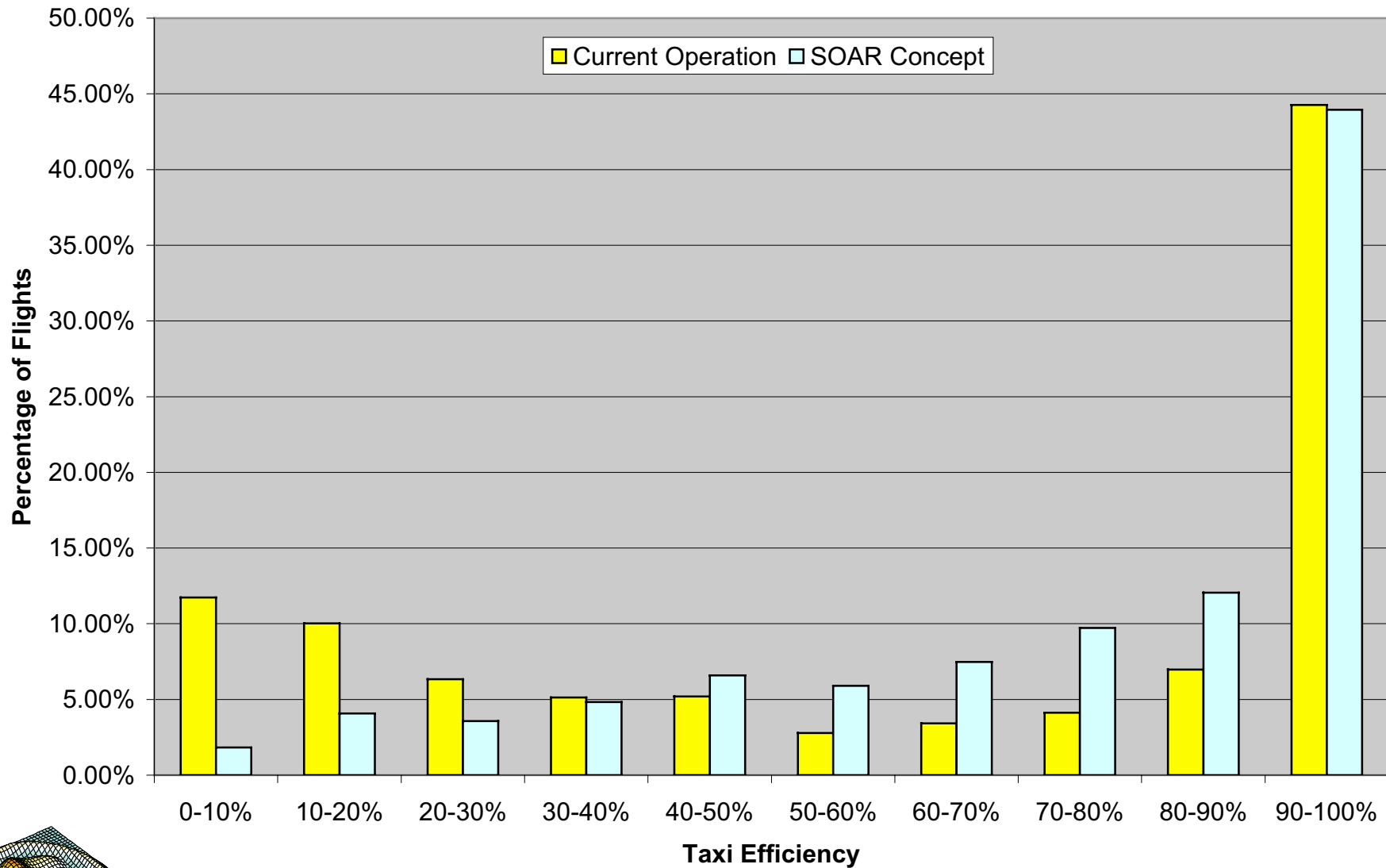
# Relationship between Taxi Efficiency and Throughput for 250-Airport Demand: Current Ops vs SOAR Concept



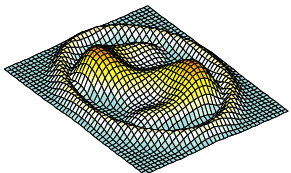
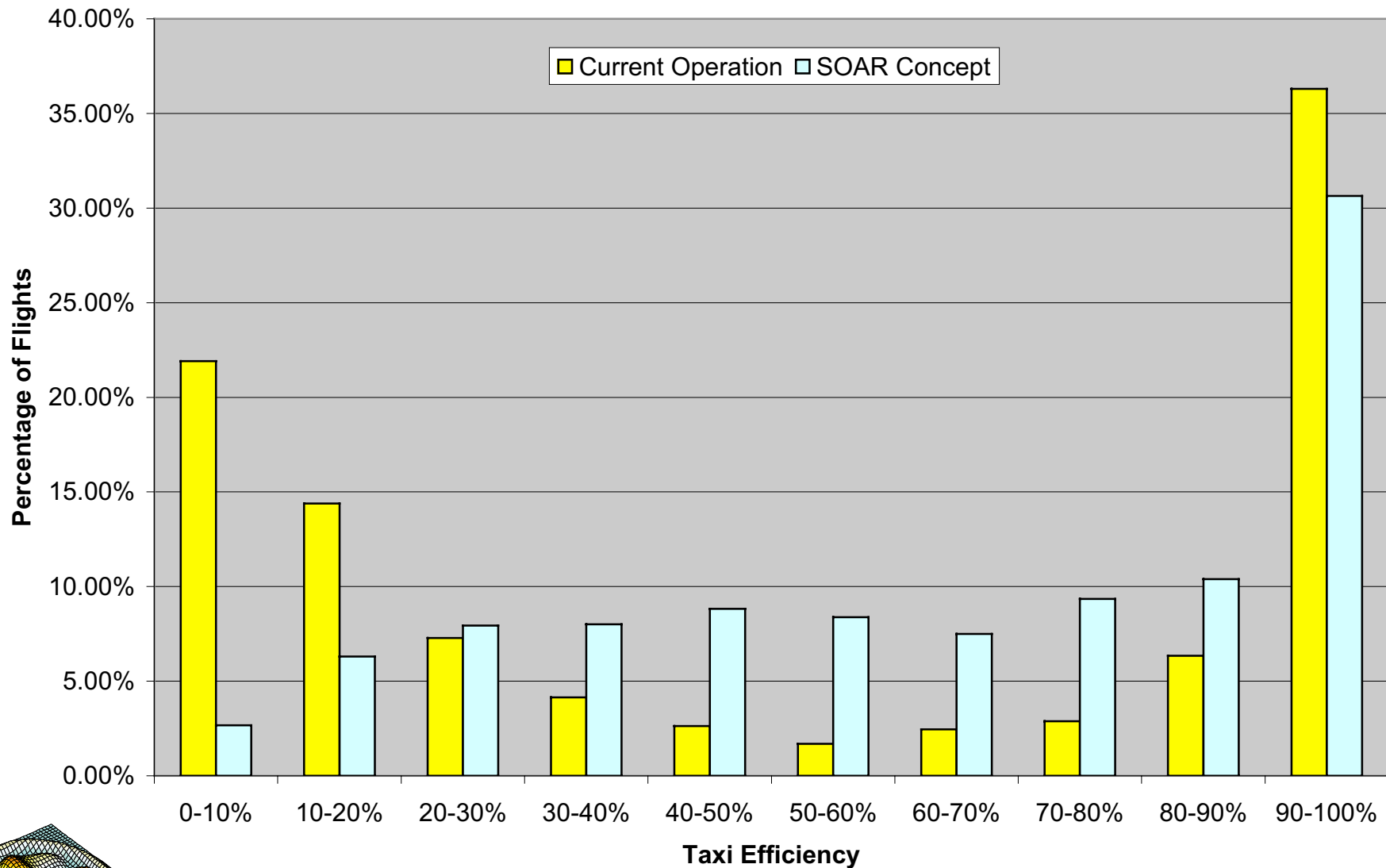
# Relationship between Taxi Efficiency and Throughput for Future Demand: Current Ops vs SOAR Concept



# Histogram of Taxi Efficiencies for 250-Airport Demand Set

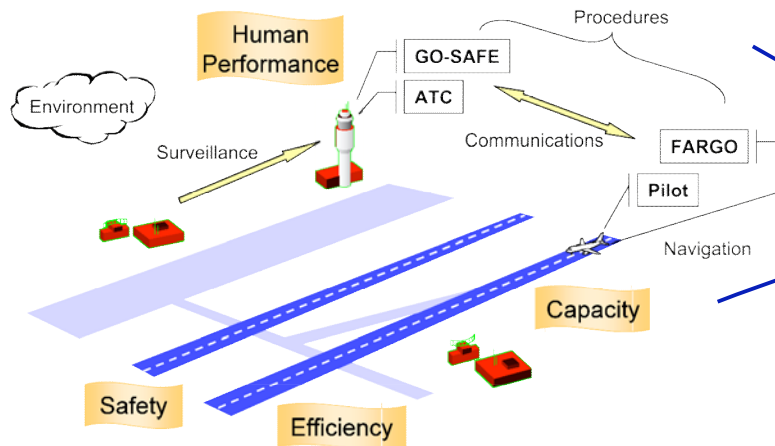
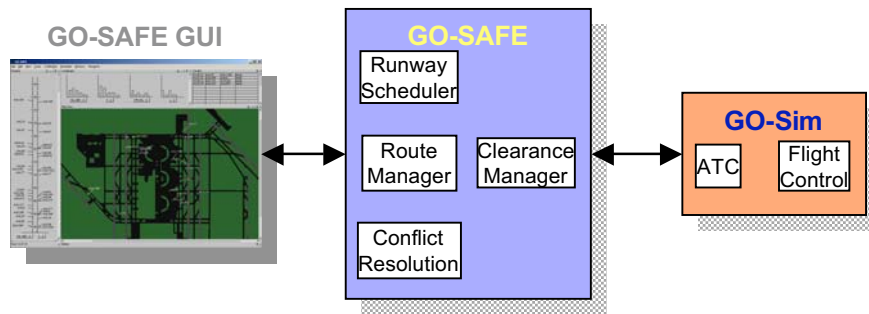


# Histogram of Taxi Efficiencies for Future Demand Set

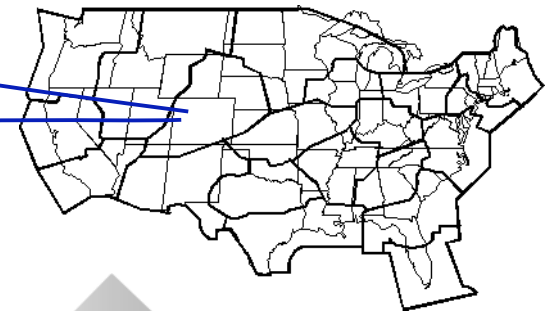


# Relationship with Future Work

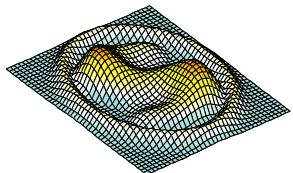
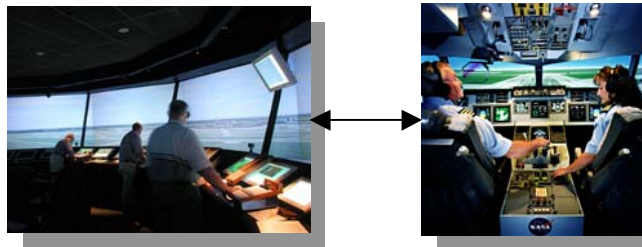
## Surface-Domain Computer-Simulation Evaluation



## ACES NAS-Wide Assessment



## Real-Time Human-in-the-Loop Evaluation

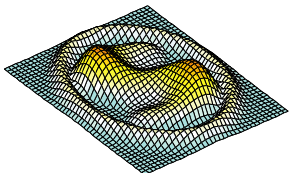


TIM 2/11/2004

# Challenges for Future Analyses

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- **Metrics quantifiable with average behavior are good candidates for evaluation with computer simulations: e.g. throughputs, taxi delays, etc.**
- **Certain factors are unsuitable for evaluation with computer simulations:**
  - **Modeling of human performance in computer simulations is necessarily inexact: human-in-the-loop evaluation is needed to assess human-performance factors, e.g., workload, human error, etc.**
  - **Certain factors are highly dependent on technology and implementation details: e.g., safety, security, reliability, etc.**
- **For Phase III ACES evaluation:**
  - **Effects of demand on throughputs and taxi efficiencies may be included for assessment through proper parameterization.**
  - **Ripple effect of taxi delays on hub connections would require adequate modeling of departure delays due to arrival bank delays.**



# Ripple Effect of Taxi Delays

